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13. ABSTRACT (Maximum 200 words)

We developed a mK scanning tunneling microscope whereby we can interrogate the wavefunction of donor states at individual dopant atoms to determines if they are useful as qubits.

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Foreword

We use high resolution STM at millikelvin temperatures (mK-STM) for allow imaging, spectroscopy, and control of the quantum wavefunctions of the electrons at individual dopant atoms in superconductors and semiconductors.

Statement of Problem

To develop a millikelvin STM capable of operation at high-fields with atomic-resolution spectroscopic mapping and its application for wavefunction imaging studies of electronic states at individual dopant atoms in several types of semiconductors.

Summary of Achievements

1. Ultra Low Vibration Laboratory at Cornell

We have completed construction and testing of a new ultra low vibration (ULV) laboratory at Cornell that is specifically designed to facilitate these projects. It consists of and underground laboratory inside which are two nested acoustic isolation rooms. The inner room is supported on six vibration isolators. Inside the inner acoustic room is the cryostat itself which is made of ~3 tons of lead and houses another massive vibration isolation stage on three isolators. The dewar and refrigerator are suspended from this stage. ***This laboratory facility exceeds (see Fig. 1c below) the stringent vibration requirements set the proposed projects and is one of the few laboratories in the world that does so.***

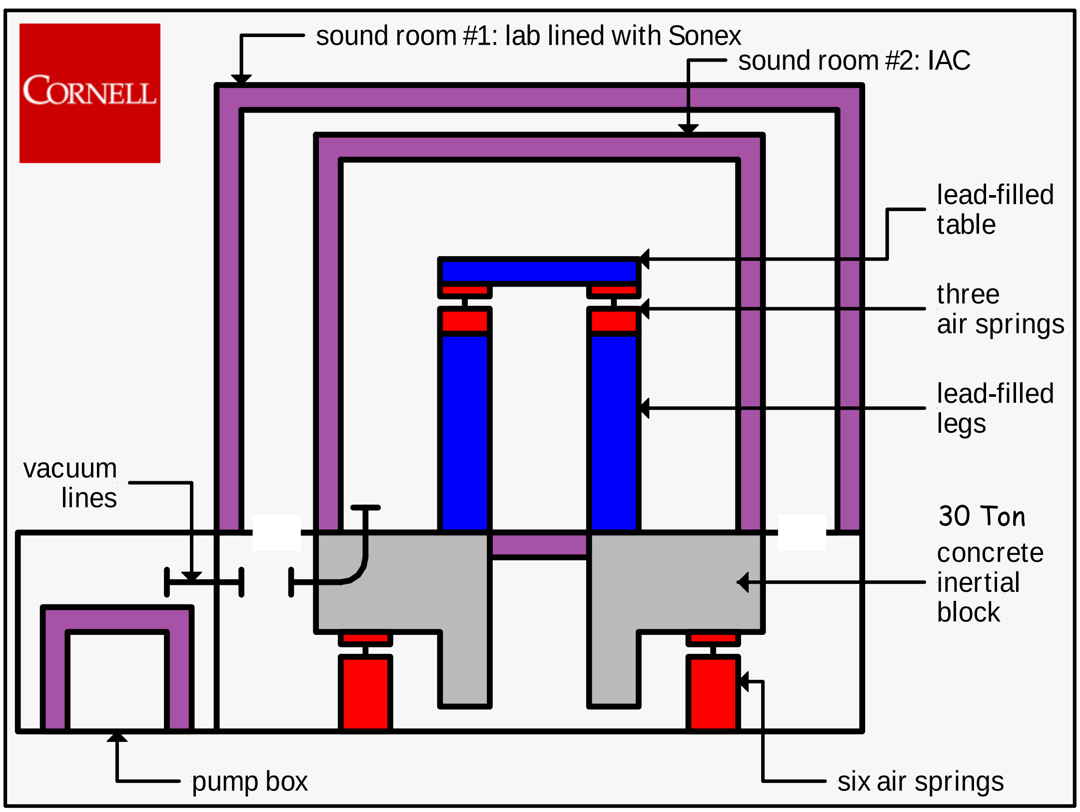

Figure 1A. The schematic of overall ULV laboratory design at Cornell. This space is about 5 meters high and 6 m square

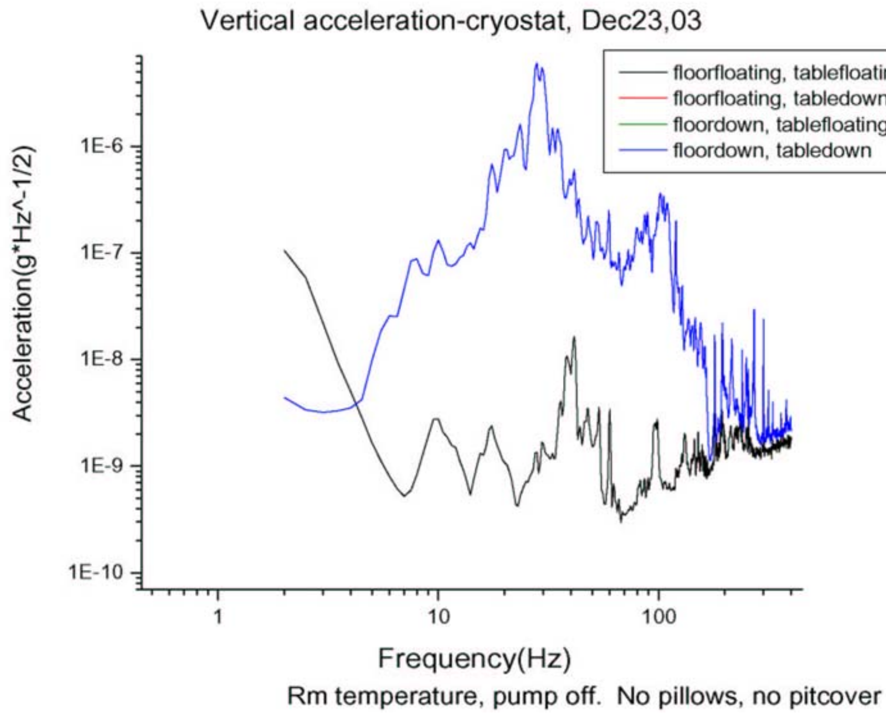

Figure 1B. The ULV lab+ cryostat performance. Measured vertical acceleration noise is suppressed into the 1 ngHz$^{-1/2}$ range for all frequencies above ~10Hz. The measurement under operating conditions (black) was made on board the refrigerator at T=0.02K while the acoustic/RF encures were closed and the two sets of air springs activated. Very similar horizontal acceleration noise isolation is also detected.

2. Millikelvin STM Installation

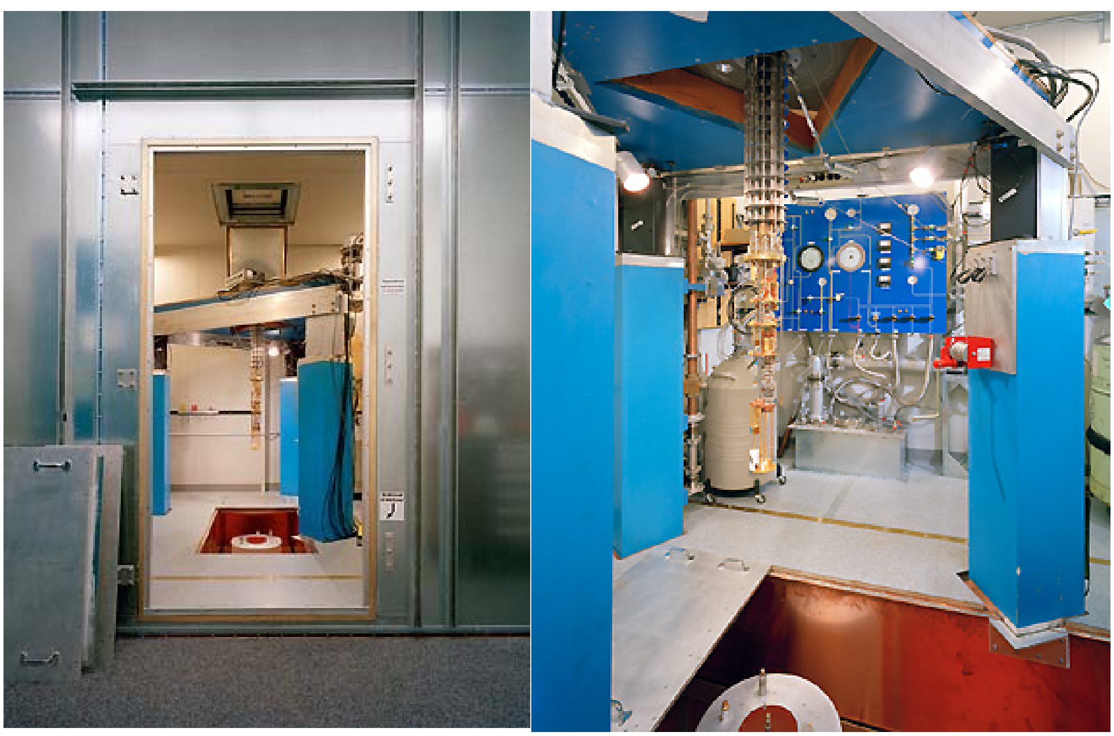

Figure 2. The ULV lab+ STM cryostat inside the RF shield/acoustic shield room. Close-up fo Dilution refrigerator.

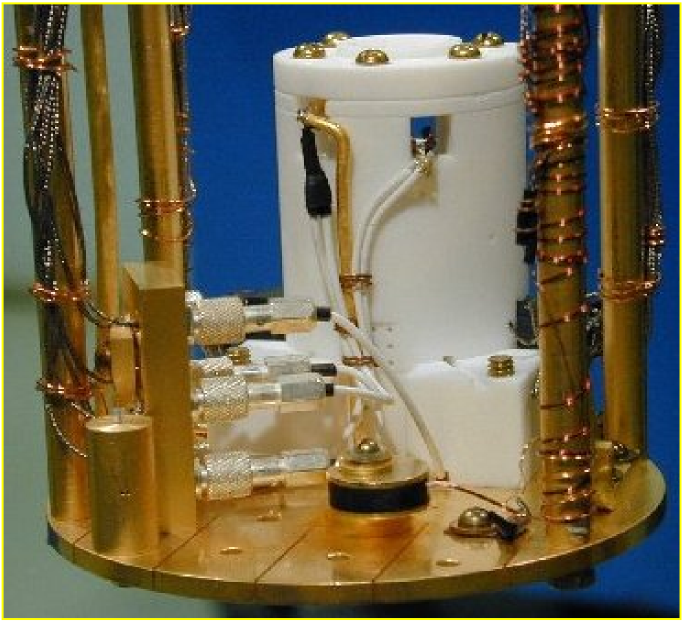

Fig.3The STM head suspended below the mixing chamber t the center of the 9T magnet (not shown)

GaAs -Te Tests.

We used the millikelvin, high-field, scanning tunneling microcopy (STM) to study the fundamental physics of bound electronic states at individual dopant atoms in a semiconductor. Although much has been said and written about electronically addressing single quantum states at dopant atoms in semiconductors, no experiments have been carried out and almost nothing is known about the applied physics of this situation. Therefore our studies were initially directed towards direct detection and study of electronic bound-states at individual dopant Te atoms (in high magnetic fields at very low temperatures) as a test case. We could identify the location of the dopant atoms, measure their spectrum and locally map the wavefunction of the donor state with spectroscopic mapping. We chose GaAs because it cleaves very nicely on the <110> plane and has a direct band gap which is observable in tunneling spectroscopy.

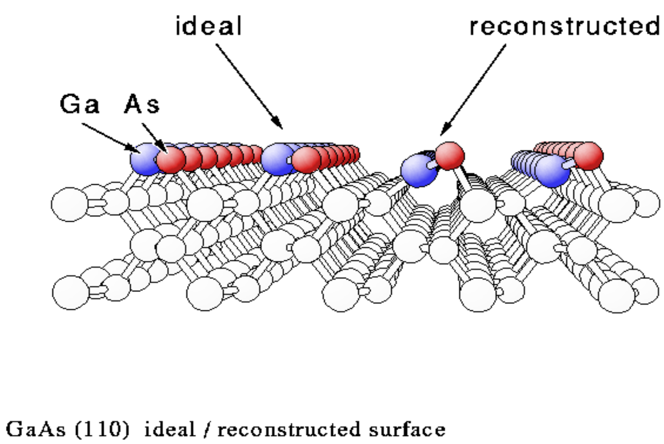

Fig. 4 Schematic of <110> cleave surface of GaAs

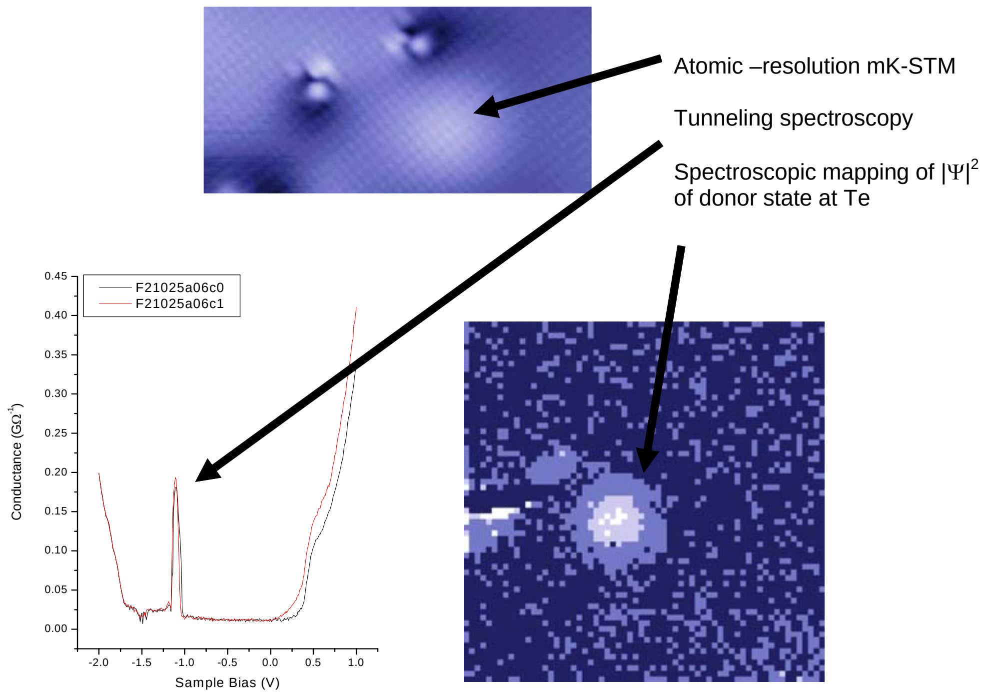

Fig. 5 Images of <110> surface of GaAs showing surface electronic defect states and the location of the Te donor atom.

When cleaved in cryogenic ultra high vacuum the surface has a small coverage of defect states which are possibly due to missing GaAs toms from the cleave or perhaps by displacement of the atoms from their correct locations in the reconstruction. In addition to these phenomena, we can see the locations of the Te dopant atoms as faint circular regions of higher LDOS. The reside approx 1.5 nm under the surface on average.

We demonstrated spectroscopic imaging of the wavefunction of the donor state. This is a *qua non* of direct manipulation of such states and the first time it has been achieved to our knowledge.

Publications

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Personnel

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